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**Trace History**

Date / Time	Location	Delivery Event Description
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02 December 2002 09:35	MISSISSAUGA, ON	The item was sent out for delivery to the customer.
02 December 2002 AM	MISSISSAUGA, ON	The customer was not available to receive the item. A card was left to advise the customer to pick up the item at their local CPC outlet.
19 December 2002 PM	MISSISSAUGA, ON	The item was refused by the customer and will be returned to the sender.
20 December 2002 07:43	TORONTO, ON	The item was sent out for delivery to the customer.
20 December 2002 AM	TORONTO, ON	The item has been successfully delivered back to the sender.



Docket No.

00001-0436

Declaration and Power of Attorney For Patent Application

English Language Declaration

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

KEY AGREEMENT & TRANSPORT PROTOCOL

the specification of which

(check one)

☐ is attached hereto.

☒ was filed on March 8, 2002 as United States Application No. or PCT International Application Number 10/092,972 and was amended on _____

(if applicable)

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119(a)-(d) or Section 365(b) of any foreign application(s) for patent or inventor's certificate, or Section 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate or PCT International application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application(s)

Priority Not Claimed

(Number)

(Country)

(Day/Month/Year Filed)

☐

(Number)

(Country)

(Day/Month/Year Filed)

☐

(Number)

(Country)

(Day/Month/Year Filed)

☐

I hereby claim the benefit under 35 U.S.C. Section 119(e) of any United States provisional application(s) listed below:

(Application Serial No.)

(Filing Date)

(Application Serial No.)

(Filing Date)

(Application Serial No.)

(Filing Date)

I hereby claim the benefit under 35 U. S. C. Section 120 of any United States application(s), or Section 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. Section 112, I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, C. F. R., Section 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application:

08/426,090

April 21, 1995

(Application Serial No.)

(Filing Date)

(Status)
(patented, pending, abandoned)

(Application Serial No.)

(Filing Date)

(Status)
(patented, pending, abandoned)

(Application Serial No.)

(Filing Date)

(Status)
(patented, pending, abandoned)

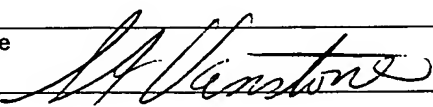
I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

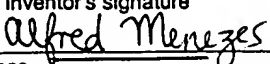
POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. *(list name and registration number)*

Orange & Chari (Customer No. 27155)

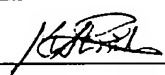
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BY REGISTERED MAIL & COURIER

November 26, 2002

Our File: 00001-0436

Minghua Qu
5495 Middlebury Drive
Mississauga ON
L5M 5G7

Dear Minghua:

Re: United States Patent Application No. **10/092,972**
For: **Key Agreement & Transport Protocol**
Applicant: **VANSTONE et al.**

Further to our conversation with you on November 11, 2002, regarding the signature of the Declaration and Power of Attorney documents, we have filed a petition to the Patent Office to allow the application to proceed. In the petition, we outlined the attempts we made to obtain your signature.


To avoid the necessity of relying on this procedure in the US Patent Office we would ask you to reconsider signing the documents. If you wish to I will explain the documents to you or to a person designated by you and the procedure to be followed if we do not obtain your signature. Therefore, I am enclosing a copy of the Application, a Declaration and Power of Attorney document for your signature. For your convenience, we have enclosed a pre-addressed envelope for returning the documents to us C.O.D. Should you decide not to sign these documents, please let us know by fax or mail.

This request is made pursuant to the Assignment of parent case US Application No. 08/426,090 that you executed on June 20, 1995 wherein you agreed to execute any and all required documentation for pursuing patent protection for the related technology.

We will of course reimburse you for any out of pocket expenses associated with responding to this letter.

Please feel free to call me if you have any questions.

Yours very truly,
ORANGE & CHARI




John R.S. Orange
JRO/AS/mh
Encl.

CANADA) TO ALL WHOM THESE PRESENTS
)
PROVINCE OF ONTARIO) MAY COME, BE SEEN OR KNOWN
)
TO WIT:)

I, DAVID GORDON ALLSEBROOK, a Notary Public in and for the Province of Ontario, by Royal Authority duly appointed, residing at the City of Toronto in said Province, DO CERTIFY AND ATTEST that the paper-writing hereto annexed is a true copy of a document produced and shown to me and purporting to be a copy of an Assignment from Scott Vanstone, Alfred John Menezes and Minghua Qu to Cryptech Systems Inc. dated June 19, 1995, the said copy having been compared by me with the said original Assignment, an act whereof being requested I have granted under my Notarial Form and Seal of Office to serve and avail as occasion shall or may require.

IN TESTIMONY WHEREOF I have hereto subscribed my name and affixed my Notarial Seal of Office at Toronto this 11th day of April, 1996



DAVID GORDON ALLSEBROOK

ASSIGNMENT

TO WHOM IT MAY CONCERN:

For the sum of One Dollar and other valuable consideration to us in hand paid, receipt of which is hereby acknowledged, be it known that we, Scott Vanstone of 539 Sandbrook Court, Waterloo, Ontario, N2T 2H4, Canada; Alfred John Menezes of 254 Payne Street, Auburn, Alabama 36830 and Mingua Qu of 157 University Avenue West, #112, Waterloo, Ontario, N2L 3E5, Canada, have sold, assigned and transferred and by these presents do sell, assign, transfer and set over unto Cryptech Systems Inc., a ✓ Ontario corporation, with a place of business at 200 Matheson Boulevard West, Mississauga, Ontario, L5R 3L7, Canada, its successors, legal representatives, or assigns, the whole right, title and interest in and to a certain invention relating to an KEY AGREEMENT AND TRANSPORT PROTOCOL by us devised and the application for United States Patent therefor executed by us and filed in the United States Patent and Trademark Office on April 21, 1995, Serial No. 08/426,090, and all original and reissue patents granted thereof, and all divisions and continuations thereof, including the subject matter of any and all claims which may be obtained in every such patent, and all foreign rights to said invention, and covenant that we have full right to do so, and agree that we will communicate to said corporation or its representatives all facts known to us respecting said invention, whenever requested, and testify in any legal proceedings, sign all lawful papers, make all rightful oaths and generally do

everything possible to aid said corporation, its successors, assigns, and nominees, to obtain and enforce proper patent protection for said invention in all countries.

The Commissioner of Patents and Trademarks is requested to issue the Letters Patent which may be granted for said invention or any part thereof unto the said corporation in keeping with this Assignment.

Date: June 19, 1995

Scott Vanstone
Scott Vanstone

M. Calhoun
(WITNESS)

Date: June 19, 1995

A. Menezes
Alfred John Menezes

Robert Z. Z. Z.
(WITNESS)

Date: June 20, 1995

Mingua Qu
MINGUA QU

M. Calhoun
(WITNESS)

KEY AGREEMENT AND TRANSPORT PROTOCOL

This application is a continuation-in-part of United States Application No. 08/426,090.

The present invention relates to key agreement protocols for transfer and authentication of encryption keys.

To retain privacy during the exchange of information it is well known to encrypt data using a key. The key must be chosen so that the correspondents are able to encrypt and decrypt messages but such that an interceptor cannot determine the contents of the message.

In a secret key cryptographic protocol, the correspondents share a common key that is secret to them. This requires the key to be agreed upon between the correspondents and for provision to be made to maintain the secrecy of the key and provide for change of the key should the underlying security be compromised.

Public key cryptographic protocols were first proposed in 1976 by Diffie-Hellman and utilized a public key made available to all potential correspondents and a private key known only to the intended recipient. The public and private keys are related such that a message encrypted with the public key of a recipient can be readily decrypted with the private key but the private key cannot be derived from the knowledge of the plaintext, ciphertext and public key.

Key establishment is the process by which two (or more) parties establish a shared secret key, called the session key. The session key is subsequently used to achieve some cryptographic goal, such as privacy. There are two kinds of key agreement protocol; key transport protocols in which a key is created by one party and securely transmitted to the second party; and key agreement protocols, in which both parties contribute information which jointly establish the shared secret key. The number of message exchanges required between the parties is called the number of passes. A key establishment protocol is said to provide implicit key authentication (or simply key authentication) if one party is assured that no other party aside from a specially identified second party may learn the value of the session key. The property of implicit key authentication does not necessarily mean that the second party actually

1 possesses the session key. A key establishment protocol is said to provide key
2 confirmation if one party is assured that a specially identified second party actually
3 has possession of a particular session key. If the authentication is provided to both
4 parties involved in the protocol, then the key authentication is said to be mutual if
5 provided to only one party, the authentication is said to be unilateral.

6 There are various prior proposals which claim to provide implicit key
7 authentication.

8 Examples include the Nyberg-Rueppel one-pass protocol and the
9 Matsumoto-Takashima-Imai (MTI) and the Goss and Yacobi two-pass protocols for
10 key agreement.

11 The prior proposals ensure that transmissions between correspondents
12 to establish a common key are secure and that an interloper cannot retrieve the session
13 key and decrypt the ciphertext. In this way security for sensitive transactions such as
14 transfer of funds is provided.

15 For example, the MTI/A0 key agreement protocol establishes a shared
16 secret K, known to the two correspondents, in the following manner:-

17 1. During initial, one-time setup, key generation and publication is
18 undertaken by selecting and publishing an appropriate system prime p and generator
19 in a manner guaranteeing authenticity. Correspondent A selects as a long-term private
20 key a random integer "a", $1 \leq a \leq p-2$, and computes a long-term public key $z_A = \alpha^a \text{ mod } p$.
21 B generates analogous keys b, z_B . A and B have access to authenticated copies of
22 each other's long-term public key.

23 2. The protocol requires the exchange of the following messages.

24 $A \rightarrow B: \alpha^x \text{ mod } p$ (1)

25 $A \leftarrow B: \alpha^y \text{ mod } p$ (2)

26 The values of x and y remain secure during such transmissions as it is
27 impractical to determine the exponent even when the value of α and the
28 exponentiation is known provided of course that p is chosen sufficiently large.

29 3. To implement the protocol the following steps are performed each time
30 a shared key is required.

- 1 (a) A chooses a random integer $x, 1 \leq x \leq p-2$, and sends B message
2 (1) i.e. $\alpha^x \bmod p$.
3 (b) B chooses a random integer $y, 1 \leq y \leq p-2$, and sends A message
4 (2) i.e. $\alpha^y \bmod p$.
5 (c) A computes the key $K = (\alpha^y)^a z_B^x \bmod p$.
6 (d) B computes the key $K = (\alpha^x)^b z_A^y \bmod p$.
7 (e) Both share the key $K = \alpha^{bx+ay}$.

8
9 In order to compute the key K , A must use his secret key a and the
10 random integer x , both of which are known only to him. Similarly B must use her
11 secret key b and random integer y to compute the session key K . Provided the secret
12 keys a, b remain uncompromised, an interloper cannot generate a session key identical
13 to the other correspondent. Accordingly, any ciphertext will not be decipherable by
14 both correspondents.

15 As such this and related protocols have been considered satisfactory for
16 key establishment and resistant to conventional eavesdropping or man-in-the-middle
17 attacks.

18 In some circumstances it may be advantageous for an adversary to
19 mislead one correspondent as to the true identity of the other correspondent.

20 In such an attack an active adversary or interloper E modifies messages
21 exchanged between A and B, with the result that B believes that he shares a key K
22 with E while A believes that she shares the same key K with B. Even though E does
23 not learn the value of K the misinformation as to the identity of the correspondents
24 may be useful.

25 A practical scenario where such an attack may be launched
26 successfully is the following. Suppose that B is a bank branch and A is an account
27 holder. Certificates are issued by the bank headquarters and within the certificate is
28 the account information of the holder. Suppose that the protocol for electronic deposit
29 of funds is to exchange a key with a bank branch via a mutually authenticated key
30 agreement. Once B has authenticated the transmitting entity, encrypted funds are

1 deposited to the account number in the certificate. If no further authentication is done
2 in the encrypted deposit message (which might be the case to save bandwidth) then
3 the deposit will be made to E's account.

4 It is therefore an object of the present invention to provide a protocol in
5 which the above disadvantages are obviated or mitigated.

6 According therefore to the present invention there is provided a method
7 of authenticating a pair of correspondents A,B to permit exchange of information
8 therebetween, each of said correspondents having a respective private key a,b and a
9 public key p_A,p_B derived from a generator α and respective ones of said private keys
10 a,b , said method including the steps of

11 i) a first of said correspondents A selecting a first random integer x and
12 exponentiating a function $f(\alpha)$ including said generator to a power $g^{(x)}$ to provide a
13 first exponentiated function $f(\alpha)^{g^{(x)}}$;

14 ii) said first correspondent A forwarding to a second correspondent B a message
15 including said first exponentiated function $f(\alpha)^{g^{(x)}}$;

16 iii) said correspondent B selecting a second random integer y and exponentiating a
17 function $f(\alpha)$ including said generator to a power $g^{(y)}$ to provide a second
18 exponentiated function $f(\alpha)^{g^{(y)}}$;

19 iv) said second correspondent B constructing a session key K from information
20 made public by said first correspondent A and information that is private to said
21 second correspondent B, said session key also being constructible by said first
22 correspondent A for information made public by B and information that is private to
23 said first correspondent A;

24 v) said second correspondent B generating a value h of a function $F[\delta,K]$
25 where $F[\delta,K]$ denotes a cryptographic function applied conjointly to δ and K and
26 where δ is a subset of the public information provided by B thereby to bind the values
27 of δ and K ;

28 vi) said second of said correspondents B forwarding a message to said first
29 correspondent A including said second exponential function $f(\alpha)^{g^{(y)}}$ and said value h
30 of said cryptographic function $F[\delta,K]$;

- 1 vii) said first correspondent receiving said message and computing a session key
2 K' from information made public by said second correspondent B and private to said
3 first correspondent A;
4 viii) said first correspondent A computing a value h' of a cryptographic function
5 h,h' F[δ ,K']; and
6 ix) comparing said values obtained from said cryptographic functions F to
7 confirm their correspondence.

8 As the session key K can only be generated using information that is
9 private to either A or B, the binding of K with δ with the cryptographic function h
10 prevents E from extracting K or interjecting a new value function that will correspond
11 to that obtained by A.

12 Embodiments of the invention will now be described by way of
13 example only with reference to the accompanying drawings in which.

14 Figure 1 is a schematic representation of a data communication system.

15 Figures 2 through 7 are schematic representations of implementations
16 of different protocols.

17 Referring therefore to Figure 1, a pair of correspondents, 10,12,
18 denoted as correspondent A and correspondent B, exchange information over a
19 communication channel 14. A cryptographic unit 16,18 is interposed between each of
20 the correspondents 10,12 and the channel 14. A key 20 is associated with each of the
21 cryptographic units 16,18 to convert plaintext carried between each unit 16,18 and its
22 respective correspondent 10,12 into ciphertext carried on the channel 14.

23 In operation, a message generated by correspondent A, 10, is encrypted
24 by the unit 16 with the key 20 and transmitted as ciphertext over channel 14 to the
25 unit 18.

26 The key 20 operates upon the ciphertext in the unit 18 to generate a
27 plaintext message for the correspondent B, 12. Provided the keys 20 correspond, the
28 message received by the correspondent 12 will be that sent by the correspondent 10.

29 In order for the system shown in Figure 1 to operate it is necessary for
30 the keys 20 to be identical and therefore a key agreement protocol is established that

1 allows the transfer of information in a public manner to establish the identical keys. A
2 number of protocols are available for such key generation and embodiments of the
3 present invention will be described below in the context of modifications of existing
4 protocols.

5 A commonly used set of protocols are collectively known as the
6 Matsumoto-Takashima-Imai or "MTI" key agreement protocols, and are variants of
7 the Diffie-Hellman key exchange. Their purpose is for parties A and B to establish a
8 secret session key K.

9 The system parameters for these protocols are a prime number p and a
10 generator α of the multiplicative group

11 . Correspondent A has private key a and public key $p_A = \alpha^a$. Correspondent B has
12 private key b and public key $p_B = \alpha^b$. In all four protocols exemplified below, text_A
13 refers to a string of information that identifies party A. If the other correspondent B
14 possesses an authentic copy of correspondent A's public key, then text_A will contain
15 A's public-key certificate, issued by a trusted center; correspondent B can use his
16 authentic copy of the trusted center's public key to verify correspondent A's certificate,
17 hence obtaining an authentic copy of correspondent A's public key.

18 In each example below it is assumed that an interloper E wishes to
19 have messages from A identified as having originated from E herself. To accomplish
20 this, E selects a random integer e, $1 \leq e \leq p-2$, computes $p_E = (p_A)^e = \alpha^{ae} \bmod p$, and gets
21 this certified as her public key. E does not know the exponent ae, although she knows
22 e. By substituting text_E for text_A , the correspondent B will assume that the message
23 originates from E rather than A and use E's public key to generate the session key K.
24 E also intercepts the message from B and uses his secret random integer e to modify
25 its contents. A will then use that information to generate the same session key
26 allowing A to communicate with B.

27 The present invention is exemplified by modifications to 4 of the
28 family of MTI protocols which foil this new attack thereby achieving the desired
29 property of mutual implicit authentication. In the modified protocols exemplified
30 below $F(X,Y)$ denotes a cryptographic function applied to a string derived from x and

1 y. Typically and as exemplified a hash function, such as the NIST "Secure Hash
2 Algorithm"(SHA-1), is applied to the string obtained by concatenating X and Y but it
3 will be understood that other cryptographic functions may be used.

4 **Example 1 - MTI/A0 protocol**

5 The existing protocol operates as follows:-

- 6 1. Correspondent A generates a random integer
7 $x, 1 \leq x \leq p-2$, computes α^x , and sends $\{\alpha^x, \text{text}_A\}$ to party B.
- 8 2. Correspondent B generates a random integer
9 $y, 1 \leq y \leq p-2$, computes α^y , and sends $\{\alpha^y, \text{text}_B\}$ to party A.
- 10 3. Correspondent A computes $K = (\alpha^y)^a (p_B)^x = \alpha^{ay+bx}$.
- 11 4. Correspondent B computes $K = (\alpha^x)^b (p_A)^y = \alpha^{ay+bx}$.

12
13 A common key K is thus obtained. However, with this arrangement,
14 interloper E may have messages generated by correspondent A identified as having
15 originated from E in the following manner.

- 16 1. E intercepts A's message $\{\alpha^x, \text{text}_A\}$ and replaces it with $\{\alpha^x, \text{text}_E\}$.
17 The provision of the message text_E identifies the message as having originated at E.
- 18 2. B sends $\{\alpha^y, \text{text}_B\}$ to E, who then forwards $\{(\alpha^y)^e, \text{text}_B\}$ to A. Since A
19 receives text_B , he assumes the message originates at B and, as he does not know the
20 value of y, assumes that α^{ye} is valid information.
- 21 3. A computes $K = (\alpha^{ey})^a (p_B)^x = \alpha^{aey+bx}$.
- 22 4. B computes $K = (\alpha^x)^b (p_E)^y = \alpha^{aey+bx}$.
- 23 5. A and B now share the key K, even though B believes he shares a key
24 with E.

25
26 Accordingly any further transactions from A to B will be considered by
27 B to have originated at E. B will act accordingly crediting instruction to E. Even
28 though the interloper E does not learn the value of the session key K nevertheless the
29 assumption that the message originates at E may be valuable and achieve the desired
30 effect.

1 To avoid this problem, the protocol is modified as follows:-

2 1. A generates a random integer $x, 1 \leq x \leq p-2$, computes α^x , and sends
3 $\{\alpha^x, \text{text}_A\}$ to party B.

4 2. B generates a random integer $y, 1 \leq y \leq p-2$, and computes α^y , K
5 $= (\alpha^x)^y = (\alpha^y)^x = \alpha^{xy}$, and a value h of cryptographic hash function $F(\alpha^y, \alpha^{xy})$ which is a
6 function of public information δ and the key K . B sends $\{\alpha^y, h, \text{text}_B\}$ to party A.

7 3. A computes $K = (\alpha^y)^x = (\alpha^x)^y = \alpha^{xy}$. A also computes a value h' of
8 cryptographic hash function $F(\alpha^y, K)$ and verifies that this value is equal to h .

9
10 If E attempts to interpose her identification, text_E , the attack fails on
11 the modified protocols because in each case B sends the hash value $F(\delta, K)$, where δ is
12 B's random exponential, α^y , thereby binding together the values of δ and K . E cannot
13 subsequently replace the value of δ with δ^e and compute $F(\delta^e, K)$ since E does not
14 know K . Even though E knows α^y , this is not sufficient to extract K from the hash
15 value h . Accordingly, even if E interposes the value α^{ye} so that the keys will agree,
16 the values h, h' will not.

17

18 Example 2 - MTI/B0 protocol

19 In this protocol,

20 1. A generates a random integer $x, 1 \leq x \leq p-2$, computes $(p_B)^x = \alpha^{bx}$, and
21 sends $\{\alpha^{bx}, \text{text}_A\}$ to party B.

22 2. B generates a random integer $y, 1 \leq y \leq p-2$, computes $(p_A)^y = \alpha^{ay}$, and
23 sends $\{\alpha^{ay}, \text{text}_B\}$ to party A.

24 3. A computes $K = (\alpha^{ay})^x \alpha^{bx} = \alpha^{x+y}$

25 4. B computes $K = (\alpha^{bx})^y \alpha^{ay} = \alpha^{x+y}$

26

27 This protocol is vulnerable to the interloper E if,

28 1. E replaces A's message $\{\alpha^{bx}, \text{text}_A\}$ with $\{\alpha^{bx}, \text{text}_E\}$ to identify herself
29 as the originator to the message.

30 2. B sends $\{(p_E)^y, \text{text}_B\}$ to E, who then computes

1 $((P_E)^y)^{e^{-1}} = \alpha^{ay}$ and forwards $\{\alpha^{ay}, \text{text}_B\}$ to A.

2 3. A computes $K = (\alpha^{ay})^{a^{-1}} \alpha^x = \alpha^{x+ay}$

3 4. B computes $K = (\alpha^{bx})^{b^{-1}} \alpha^y = \alpha^{x+ay}$

4 5. A and B now share the key K, even though B believes he shares a key
5 with E.

6

7 This protocol may be modified to resist E's attack as follows.

8 1. A generates a random integer $x, 1 \leq x \leq p-2$, computes $(p_B)^x = \alpha^{bx}$, and
9 sends $\{\alpha^{bx}, \text{text}_A\}$ to party B.

10 2. B generates a random integer $y, 1 \leq y \leq p-2$, and computes $(p_A)^y = \alpha^{ay}$,
11 $K = (\alpha^{bx}) \alpha^y = \alpha^{x+ay}$, and the value h of hash function $F(\alpha^y = \alpha^{x+ay})$. B
12 sends $\{\alpha^{ay}, h, \text{text}_B\}$ to A.

13 3. A computes $K = (\alpha^{ay}) \alpha^x = \alpha^{x+ay}$. A also computes the value h' of hash
14 function $F(\alpha^{ay}, K)$ and verifies that this value is equal to h .

15 Once again, E cannot determine the session key K and so cannot
16 generate a new value of the hash function to maintain the deception.

17 **Example 3 - MTI/CO protocol**

18 This protocol operates as follows:-

19 1. A generates a random integer $x, 1 \leq x \leq p-2$, computes $(p_B)^x = \alpha^{bx}$, and
20 sends $\{\alpha^{bx}, \text{text}_A\}$ to party B.

21 2. B generates a random integer $y, 1 \leq y \leq p-2$, computes $(p_A)^y = \alpha^{ay}$, and
22 sends $\{\alpha^{ay}, \text{text}_B\}$ to party A.

23 3. A computes $K = (\alpha^{ay})^{a^{-1}x} = \alpha^{xy}$

24 4. B computes $K = (\alpha^{bx})^{b^{-1}y} = \alpha^{xy}$

25

26 The interloper E may interpose her identity as follows:-

27 1. E replaces A's message $\{\alpha^{bx}, \text{text}_A\}$ with $\{\alpha^{bx}, \text{text}_E\}$.

28 2. B sends $\{(p_E)^y, \text{text}_B\}$ to E, who then computes $((p_E)^y)^{e^{-1}} = \alpha^{ay}$ and
29 forwards $\{\alpha^{ay}, \text{text}_B\}$ to A.

- 1 3. A computes $K = (\alpha^{ay})^{a^{-1}x} = \alpha^{xy}$
- 2 4. B computes $K = (\alpha^{bx})^{b^{-1}y} = \alpha^{xy}$
- 3 5. A and B now share the key K, even though B believes he shares a key
- 4 with E.
- 5
- 6 To avoid this attack protocol is modified as follows:-
- 7 1. A generates a random integer $x, 1 \leq x \leq p-2$, computes $(p_B)^x = \alpha^{bx}$, and
- 8 sends $\{\alpha^{bx}, \text{text}_A\}$ to party B.
- 9 2. B generates a random integer $y, 1 \leq y \leq p-2$, and computes
- 10 $(p_A)^y = \alpha^{ay}$, $K = (\alpha^{bx})^{b^{-1}y} = \alpha^{xy}$, and value
- 11 h of hash function $F(\alpha^{ay}, \alpha^{xy})$. B sends $\{\alpha^{ay}, h, \text{text}_B\}$ to party A.
- 12 3. A computes $K = (\alpha^{ay})^{a^{-1}x} = \alpha^{xy}$. A also computes the value h' of
- 13 $F(\alpha^{ay}, K)$ and verifies that this value is equal to h.

1 Example 4 - MTI/C1 protocol

2 In this protocol:-

- 3 1. A generates a random integer $x, 1 \leq x \leq p-2$, computes $(p_B)^{ax} = \alpha^{abx}$, and
4 sends $\{\alpha^{abx}, \text{text}_A\}$ to party B.
- 5 2. B generates a random integer $y, 1 \leq y \leq p-2$, computes $(p_A)^{by} = \alpha^{aby}$, and
6 sends $\{\alpha^{aby}, \text{text}_B\}$ to party A.
- 7 3. A computes $K = (\alpha^{aby})^x = \alpha^{abxy}$.
- 8 4. B computes $K = (\alpha^{abx})^y = \alpha^{abxy}$.

9
10 E can act as an interloper as follows:-

- 11 1. E replaces A's message $\{\alpha^{abx}, \text{text}_A\}$ with $\{\alpha^{abx}, \text{text}_E\}$.
- 12 2. B sends $\{(p_E)^{by}, \text{text}_B\}$ to E, who then computes $((p_E)^{by})^{c-1} = \alpha^{aby}$ and
13 forwards $\{\alpha^{aby}, \text{text}_B\}$ to A.
- 14 3. A computes $K = (\alpha^{aby})^x = \alpha^{abxy}$.
- 15 4. B computes $K = (\alpha^{abx})^y = \alpha^{abxy}$.
- 16 5. A and B now share the key K, even though B believes he shares a key
17 with E.

18
19 To avoid this, the protocol is modified as follows:-

- 20 1. A generates a random integer $x, 1 \leq x \leq p-2$, computes $(p_B)^{ax} = \alpha^{abx}$, and
21 sends $\{\alpha^{abx}, \text{text}_A\}$ to party B.
- 22 2. B generates a random integer $y, 1 \leq y \leq p-2$, and computes $(p_A)^{by} = \alpha^{aby}$, K
23 $= (\alpha^{abx})^y = \alpha^{abxy}$, and
24 $h = F(\alpha^{aby}, \alpha^{abxy})$. B sends $\{\alpha^{aby}, h, \text{text}_B\}$ to party A.
- 25 3. A computes $K = (\alpha^{aby})^x = \alpha^{abxy}$. A also computes
26 $h' = F(\alpha^{aby}, K)$ and verifies that this value is equal to h.

27
28 In each of the modified protocols discussed above, key confirmation
29 from B to A is provided.

30 As noted above instead of F being a cryptographic hash function other

1 functions could be used. For example, an option available is to choose
2 $F = E_K$, where E is the encryption function of a suitable symmetric-key encryption
3 scheme, and K is the session key established. Because E cannot generate the session
4 key K , it is similarly not able to generate the value of the function F and therefore
5 cannot interpose for the correspondent A .

6 The technique described above can be applied to other similar key
7 exchange protocols, including all of the 3 infinite classes of MTI protocols called
8 MTI-A(k), MTI-B(k) and MTI-C(k).

9 The Goss authenticated key exchange protocol is similar to the
10 MTI/A0 protocol, except that the session key is the bitwise exclusive-OR of α^{ay} and
11 α^{bx} ; that is $K = \alpha^{ay} \oplus \alpha^{bx}$ instead of being the product of α^{ay} and α^{bx} . Hence the attack
12 on the MTI/A0 protocol and its modification can be extended in a straightforward
13 manner to the case of the Goss protocol.

14 Similarly Yacobi's authenticated key exchange protocol is exactly the
15 same as the MTI/A0 protocol, except that α is an element of the group of units
16 U_n , where n is the product of 2 large primes. Again, the attack on the MTI/A0
17 protocol and its modification can be extended in a straightforward manner to the case
18 of the Goss protocol.

19 A further way of foiling the interposition of E is to require that each
20 entity prove to a trusted center that it knows the exponent of α that produces its public
21 key P , before the center issues a certificate for the public key. Because E only knows
22 "e" and not "ae" it would not meet this requirement. This can be achieved through
23 zero knowledge techniques to protect the secrecy of the private keys but also requires
24 the availability of a trusted centre which may not be convenient.

25 Each of the above examples has been described with a 2 pass protocol
26 for key authentication. One pass protocols also exist to establish a key between
27 correspondents and may be similarly vulnerable.

28 As an example the Nyberg-Rueppel one pass key agreement protocol
29 will be described and a modification proposed.

30 The purpose of this protocol is for party A and party B to agree upon a

1 secret session key K.

2 The system parameters for these protocols are a prime number p and a
3 generator α of the multiplicative group $\alpha \in Z_p^*$. User A has private key a and public
4 key $p_A = \alpha^a$. User B has private key b and public key $p_B = \alpha^b$.

5 1. A selects random integers x and t, $1 \leq x, t \leq p-2$.

6 2. B recovers the value $\alpha^x \bmod p$ by computing $\alpha^s (p_A)^r \bmod p$ and then
7 computes the shared session key $K = (r \alpha^x)^{b^{-1}} = \alpha^t \bmod p$.

8

9 If interloper E wishes to have messages from A identified as having
10 originated from herself, E selects a random integer e, $1 \leq e \leq p-2$, computes $p_E = \alpha^e$, and
11 gets this certified as her public key.

12 1. E intercepts A's message $\{r, s, \text{text}_A\}$ and computes $\alpha^x = \alpha^s (p_A)^r$ and α^{bt}
13 $= r \alpha^x$.

14 2. E then selects a random integer x' , $1 \leq x' \leq p-2$, computes $r' = \alpha^{bt} \alpha^{-x'}$
15 $\bmod p$ and $s' = x' - r'e \bmod (p-1)$.

16 3. E sends $\{r', s', \text{text}_E\}$ to B.

17 4. B recovers the value $\alpha^{s'} (p_E)^{r'} \bmod p$ and then
18 computes $\bar{K} = (r' \alpha^{s'})^{b^{-1}} = \alpha^t \bmod p$.

19 5. A and B now share the key K, even though B believes he shares a key
20 with E.

21

22 To foil such an attack the protocol is modified by requiring A to also
23 transmit a value h of $F(p_A, K)$, where F is a hash function, an encryption function of a
24 symmetric-key system with key K or other suitable cryptographic function. The
25 modified protocol is the following.

26 1. A selects random integers x and t, $1 \leq x, t \leq p-2$.

27 2. A computes $r = (p_B)^t \alpha^{-x} \bmod p$, $s = x - ra \bmod$

28 $(p-1)$, session key $K = \alpha^t \bmod p$ and the value h of hash function

29 $F(p_A, K)$. A sends $\{r, s, h, \text{text}_A\}$ to B.

1 3. B recovers the value $\alpha^x \bmod p$ by computing $\alpha^s(p_A)^r \bmod p$ and then
2 computes the shared session key $K=(r\alpha^x)^{b^{-1}} = \alpha^1 \bmod p$. B also
3 computes the value h' of function $F(p_A, K)$ and verifies that this value is
4 equal to h .

5 Again therefore by binding together the public information π and the
6 session key K in the hash function, the interposition of E will not result in identical
7 hash functions h, h' .

8 In each case it can be seen that a relatively simple modification to the
9 protocols involving the binding of public and private information in a cryptographic
10 function foils the interposition of interloper E .

11 All the protocols discussed above have been described in the setting of
12 the multiplicative group $\alpha \in Z_p^*$. However, they can all be easily modified to work in
13 any finite group in which the discrete logarithm problem appears intractable. Suitable
14 choices include the multiplicative group of a finite field (in particular the finite field
15 $GF(2^n)$), subgroups of $\alpha \in Z_p^*$ of order q , and the group of points on an elliptic curve
16 defined over a finite field. In each case an appropriate generator α will be used to
17 define the public keys.

18 The protocols discussed above can also be modified in a
19 straightforward way to handle the situation when each user picks their own system
20 parameters p and α (or analogous parameters if a group other than Z_p^* is used).

21 Further implementations are shown schematically in figures 2 through 7. A
22 different notation is utilized but it will be understood that this notation may be
23 mapped to that of the previous embodiments.

24
25 Referring to figure 2, a mutual public key authenticated key agreement protocol is
26 complemented between a correspondent A shown on the left hand side of the figure
27 and a correspondent B shown on the right hand side. Correspondent A has a public-
28 private key pair P_A, S_A respectively and similarly correspondent B has a public private

1 Key pair P_B, S_B .

2

3 As a first step, correspondent A generates a session private key as a random number

4 RND_A and computes a corresponding public session key $G_A = F_A(RND_A)$. The

5 function F_A is a cryptographic one way function, typically an exponentiation by the

6 group generator, such as a point multiplication in an elliptic curve cryptosystem.

7

8 The public session key G_A is forwarded to correspondent B who generates

9 corresponding parameters of a session private key RND_B and the exponent G_B .

10

11 The correspondent B computes a session key K as a function of A's public

12 information G_A, P_A AND B's private information RND_B, S_B . A corresponding key K'

13 can be computed by A using the private information of A and the public information

14 of B namely $f(RND_A, G_B, S_A, P_B)$.

15

16 After correspondent B has generated the key K , he compiles a string $(G_A // G_B // Id_A)$

17 where Id_A is a string that identifies A. The concatenated string is hashed with a

18 cryptographic function h_K which is a keyed hash function that uses the key K to yield a

19 string $hash_B$.

20

21 The string $hash_B$ is forwarded to correspondent A together with Id_A and G_B .

22

23 Upon receipt of the message from B, correspondent A computes the key K' as

24 described above. Correspondent A also computes a hash, $hashverify_B$ from the string

25 $(G_B // G_A // Id_A)$ using the hash function keyed by the key K' . correspondent A checks

26 that the hashes verify to confirm the identity of the keys K, K' .

27

28 Correspondent A then computes a hash h_K using the key K on the string $(G_A // G_B // Id_B)$

29 and forwards that together with Id_B correspondent B. Correspondent B similarly

30 computes a $hashverify_A$ using the keyed hash function h_K on the same string and

1 verifies that $hash_A = hashverify_A$.
 2
 3 A similar protocol is shown in figure 3 to implement a mutual symmetric key
 4 authentication protocol. In this protocol the correspondents share a key K obtained
 5 over a secure channel. The correspondents A,B, each generate a random integer which
 6 is used as the session public key of A and B respectively. Thereafter the exchange of
 7 information and verification proceeds as above with respect to figure 2 with the
 8 shared secret key being utilised in the keyed hash functions.
 9
 10 A full mutual public key authenticated protocol is shown in figure 4. An initial
 11 exchange of the public keys P_A, P_B is performed over an authenticated channel
 12 followed by the exchange of information as shown in the protocol of figure 4. In this
 13 case the correspondent A sends G_A computed as described above with respect to
 14 figure 2, together with a string x_2 that A wants confirmation of receipt by B.
 15 Correspondent B computes the key K as in figure 2 and also generates a pair of strings
 16 y_1, y_2 which B wants to have authenticated by A and receipt confirmed by A
 17 respectively. The strings are sent to A with the hash $hash_B$ and identity Id_A . The hash
 18 $hash_B$ is performed on a string including the message x_2 and the string y_1 wants
 19 authenticated.
 20
 21 Correspondent A computes the key K and verifies the hash as before. This also
 22 confirms receipt of x_2 by B.
 23
 24 Correspondent A in turn generates strings z_1, z_2 where z_1 is a string that A wants
 25 authenticated by B and z_2 is a string that may be used in a subsequent stage of the
 26 protocol described below. The strings, z_1 and y_2 together with the identifying
 27 information of B, Id_B , are included in the string that is hashed with the key K to
 28 provide the string $hash_A$. this is sent together with the identity of B and the strings
 29 z_1, z_2 to the correspondent B who can verify the hashes as before, thereby confirming
 30 receipt of y_2 and authenticating z_1 .

1
2 Thus the exchange of information is exchanged in an authenticated manner and a
3 common key obtained that allows subsequent exchange of correspondence on a secure
4 channel.
5
6 With the protocol described in figure 4 it is possible to implement a mutual public key
7 authenticated key agreement protocol by letting the strings x_2, y_1, y_2, z_1, z_2 all be empty
8 strings. Alternatively, a mutual public key authenticated key agreement protocol with
9 key transport can be implemented by using x_2 as a string that is assumed to represent
10 $E_K(k)$. Correspondent B can compute the value of K and hence retrieve the notional
11 value of k from the string. He can use this as his CRP. The values of y_1 may be used
12 to represent $E_K(k_{21})$ and z_1 as $E_K(k_{12})$ where k_{21} and k_{12} are different keys for
13 communication or other secret information to be shared between the correspondents.
14 In this case y_1 and z_2 are empty strings. In this way there is a key agreement on a
15 shared key K_{AB} together with authenticated key transport of the keys k_{21} and
16 k_{12} between the correspondents. Moreover, if additional information is provided in the
17 x_2 and y_2 then confirmation of proper receipt is also obtained.
18
19 The protocol of figure 4 may also be used to increase efficiency in successive sessions
20 by using the string z_2 to pass the information exchanged in the first pass of the next
21 session. Thus as shown in figure 5, the string G_{A,x_2} is sent as z_2 in the previous
22 session. The protocol then proceeds from correspondent B as before. Correspondent B
23 may also take advantage of this facility by including the information G_{B,y_1} for the next
24 session in the exchange as y_2 .
25
26 The mutual public key authenticated key agreement protocol may also be adapted for
27 symmetric key implementations as shown in figure 6. In this case, as in figure 3
28 above, the key generation is omitted as the correspondents have a shared key obtained
29 over a secure channel.
30

1 Similarly, the protocol of figure 6 may be modified as illustrated in figure 7 to take
2 advantage of the exchange of information in a previous session, similar to that of
3 figure 5.

4

5 It will be seen therefore that a number of versatile and flexible protocols can be
6 developed from the general protocol to meet particular needs. These protocols may
7 implement elliptic curve cryptography or operate in Z_p as preferred.

8

9

1 WE CLAIM

2

3 1. A method of authenticating a pair of correspondents A,B to permit
4 exchange of information therebetween, each of said correspondents having a
5 respective private key a,b and a public key p_A, p_B derived from a generator α and
6 respective ones of said private keys a,b, said method including the steps of

7 i) a first of said correspondents A selecting a first random integer x and
8 exponentiating a function $f(\alpha)$ including said generator to a power $g^{(x)}$ to provide a
9 first exponentiated function $f(\alpha)^{g^{(x)}}$;

10 ii) said first correspondent A forwarding to a second correspondent B a message
11 including said first exponentiated function $f(\alpha)^{g^{(x)}}$;

12 iii) said correspondent B selecting a second random integer y and exponentiating a
13 function $f(\alpha)$ including said generator to a power $g^{(y)}$ to provide a second
14 exponentiated function $f(\alpha)^{g^{(y)}}$;

15 iv) said second correspondent B constructing a session key K from information
16 made public by said first correspondent A and information that is private to said
17 second correspondent B, said session key K also being constructible by said first
18 correspondent A for information made public by B and information that is private to
19 said first correspondent A;

20 v) said second correspondent B generating a value h of a function $F[\delta, K]$
21 where $F[\delta, K]$ denotes a cryptographic function applied conjointly to δ and K and
22 where δ is a subset of the public information provided by B thereby to bind the values
23 of δ and K;

24 vi) said second of said correspondents B forwarding a message to said first
25 correspondent A including said second exponential function $f(\alpha)^{g^{(y)}}$ and said value h
26 of said cryptographic function $F[\delta, K]$;

27 vii) said first correspondent receiving said message and computing a session key
28 K' from information made public by said second correspondent B and private to said
29 first correspondent A;

30 viii) said first correspondent A computing a value h' of a cryptographic function

1 $F[\delta, K']$; and
2 ix) comparing said values obtained from said cryptographic functions F to
3 confirm their correspondence.
4
5 2. A method of claim 1 wherein said message forwarded by said first
6 correspondent includes an identification of the first correspondent.
7
8 3. A method according to claim 1 wherein said message forwarded by
9 said second correspondent includes an identification of said second correspondent.
10
11 4. A method according to claim 3 wherein said message forwarded by
12 said first correspondent includes an identification of the first correspondent.
13
14 5. A method according to claim 1 wherein said first function $f(\alpha)$
15 including said generator is said generator itself.
16
17 6. A method according to claim 1 wherein said second function $f'(\alpha)$
18 including said generator is said generator itself.
19
20 7. A method according to claim 6 wherein said first function $f(\alpha)$
21 including said generator is said generator itself.
22
23 8. A method according to claim 1 wherein said first function including
24 said generator $f(\alpha)$ includes said public key p_B of said second correspondent.
25
26 9. A method according to claim 1 wherein said second function including
27 said generator $f'\alpha$ includes said public key p_A of said first correspondent.
28
29 10. A method according to claim 1 wherein said cryptographic functions F
30 are hashes of δ and K .

1

2 11. A method of transporting a key between a pair of correspondents A,B

3 to permit exchange of information therebetween, each of said correspondents having a

4 respective private key a, b and a public key p_A, p_B derived from a generator α and

5 respective ones of said private keys a, b , said method including the steps of

6 i) a first of said correspondents A selecting a first random integer x and

7 exponentiating a function $f(\alpha)$ including said generator to a power $g^{(x)}$ to provide a

8 first exponentiated function $f(\alpha)^{g^{(x)}}$;

9 ii) said first correspondent A forwarding to a second correspondent B a message

10 including said first exponentiated function $f(\alpha)^{g^{(x)}}$;

11 iii) said second correspondent B constructing a session key K from information

12 made public by said first correspondent A and information that is private to said

13 second correspondent B, said session key K also being constructible by said first

14 correspondent A from information made public by B and information that is private to

15 said first correspondent A;

16 iv) both of said first correspondent A and said second correspondents B

17 computing a respective value h, h' of function $F[\delta, K]$ where $F[\delta, K]$ denotes a

18 cryptographic function applied to δ and K and where δ is a subset of the public

19 information provided by one of said correspondents;

20 v) at least one of said correspondents comparing said values h, h' obtained from

21 said cryptographic function F to confirm their correspondence;

22

23 12. A method of claim 11 wherein said message forwarded by said first

24 correspondent includes an identification of the first correspondent.

25

26 13. A method according to claim 11 wherein said message forwarded by

27 said first correspondent includes said value obtained from said cryptographic function

28 by said first correspondent.

29

30 14. A method according to claim 11 wherein said values obtained from

1 said cryptographic functions are obtained from a hash of said public information and
2 said session key K.

3

4 15. A method according to claim 11 wherein said first correspondent
5 selects a pair of random integers x and t and generates a session key K as $f(\alpha)^{g(t)}$, and
6 generates a value r from said first exponentiated function $f(\alpha)^{g(x)}$ which includes a
7 factor exponentiating said public key p_B of said second correspondent B with said
8 random integer t to be of the form $p_B^{E(t)\alpha^{g(x)}}$.

9

10 16. A method according to claim 15 wherein said first correspondent A
11 generates a value s from a combination of said random integer x and said private key a
12 and forwards said value of r and said value of s to said second correspondent B to
13 permit said second correspondent B to recover said session key K using the private
14 key b of said second correspondent B.

15

16 17. A method according to claim 16 wherein said random integer x and
17 said private key a are combined to produce s such that $s = x - ra \pmod{p-1}$.

18

19 18. A method according to claim 17 wherein said cryptographic function F
20 is a hash of said public information δ and said session key K .

21

22 19. A method according to claim 18 wherein said public information δ is
23 the public key p_A of said first correspondent A.

ABSTRACT

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11

A key establishment protocol includes the generation of a value of cryptographic function, typically a hash, of a session key and public information. This value is transferred between correspondents together with the information necessary to generate the session key. Provided the session key has not been compromised, the value of the cryptographic function will be the same at each of the correspondents. The value of the cryptographic function cannot be compromised or modified without access to the session key.

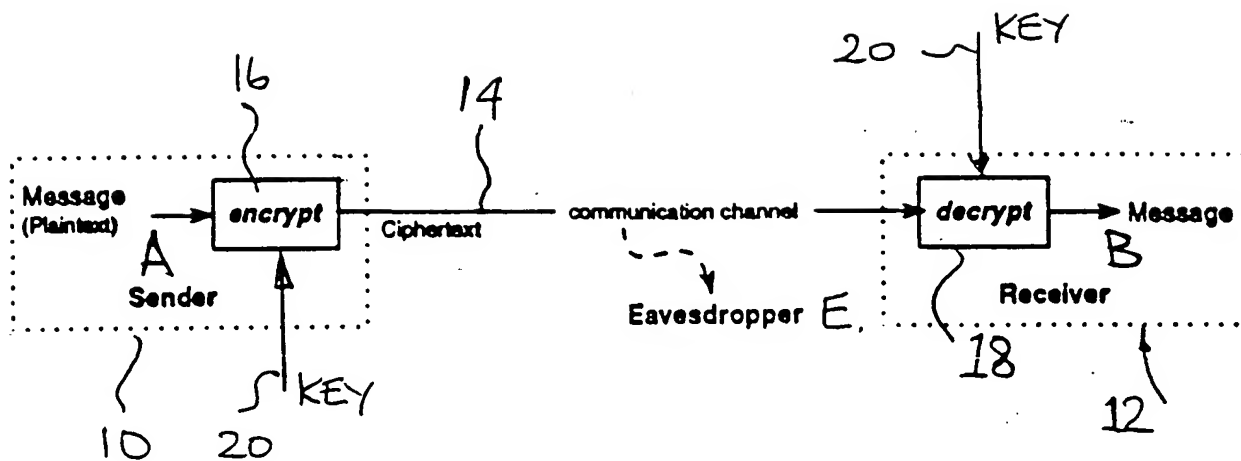


FIG. 1

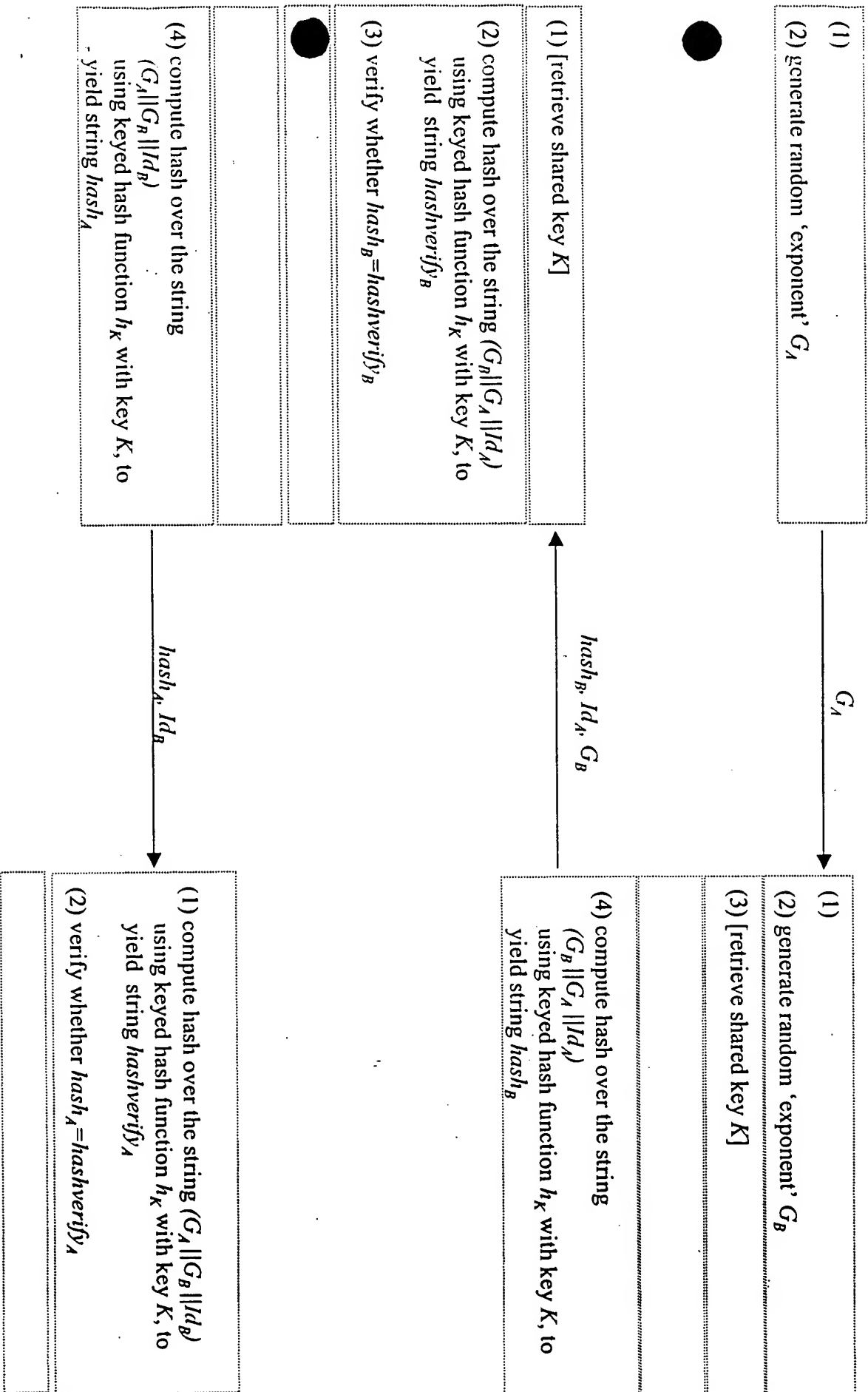
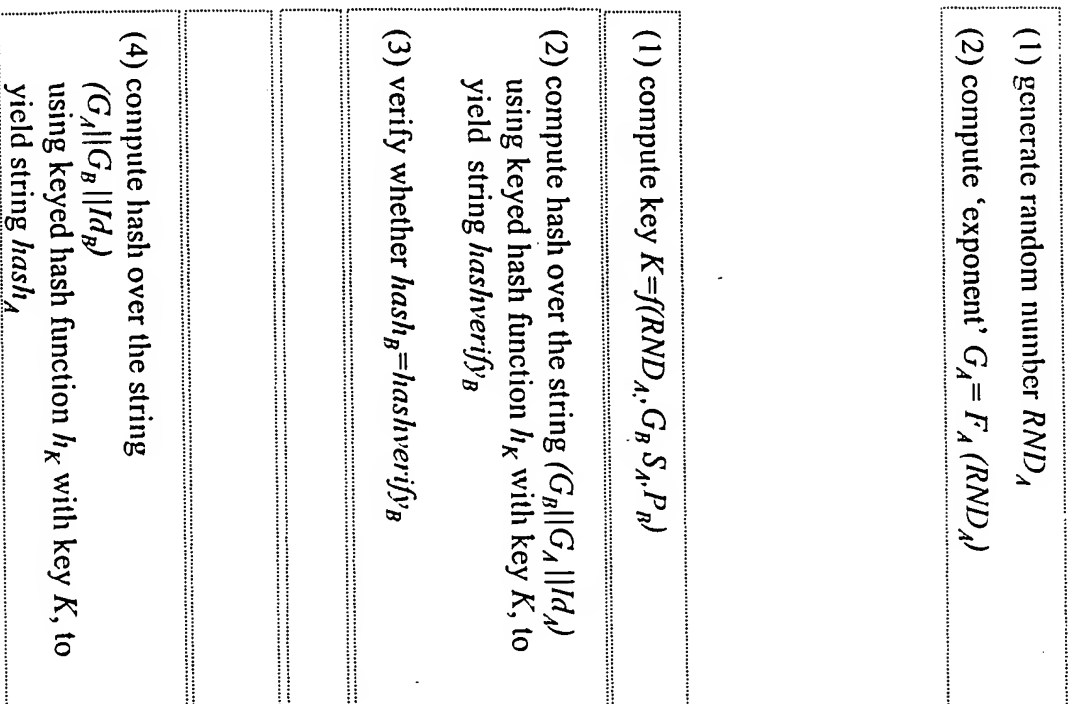


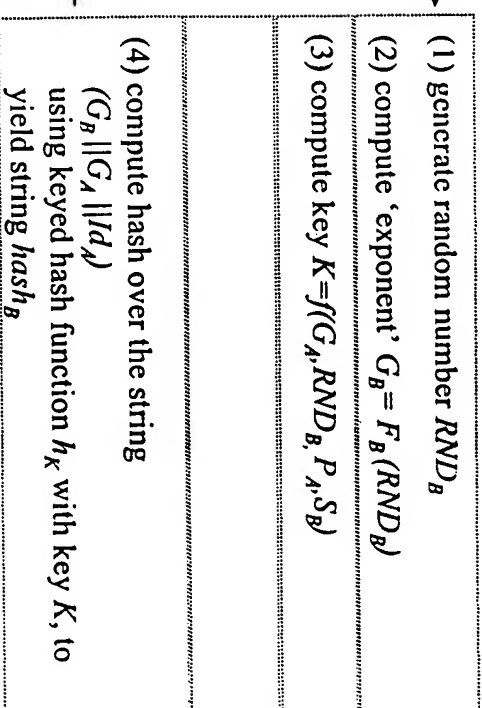
Fig 2



G_A

$hash_B, Id_A, G_B$

$hash_A, Id_B$



$$K = f(G_A, RND_B, P_A, S_B) = f(RND_A, G_B, S_A, P_B)$$

Public-private key pair $A: (P_A, S_A)$
Public-private key pair $B: (P_B, S_B)$

F_A, F_B : (trapdoor) one-way functions of A , resp. B

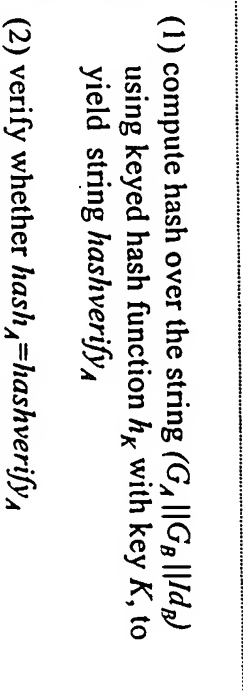
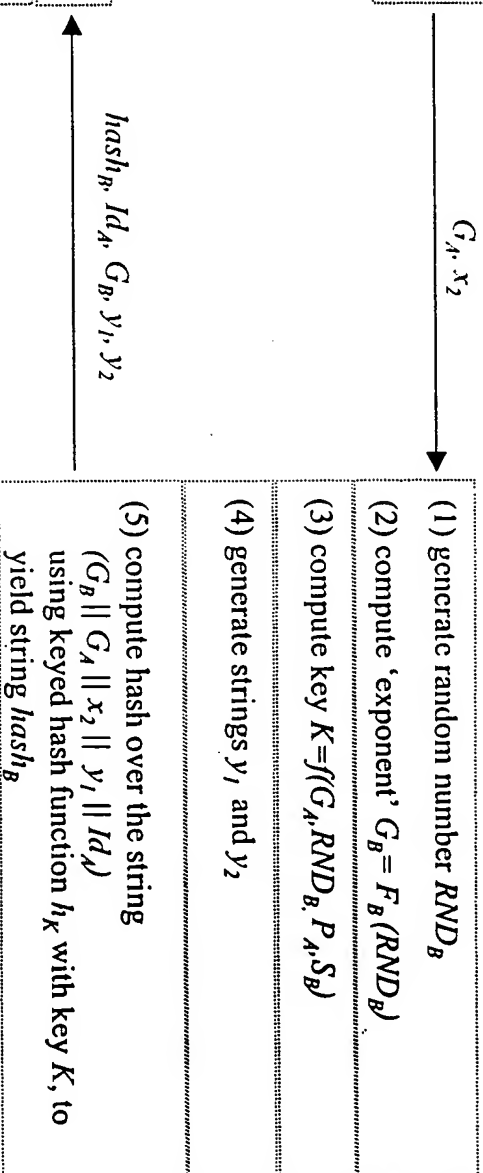
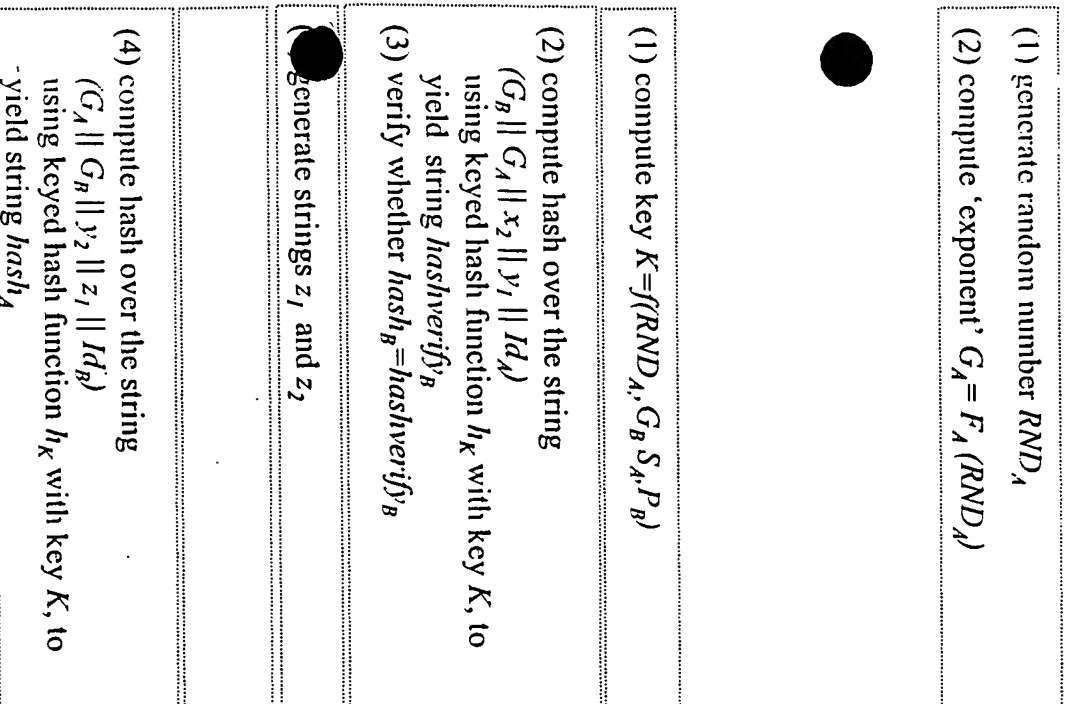


Fig 3



$K = f(G_A, RND_B, P_A, S_B)$
 $= f(RND_A, G_B, S_A, P_B)$
Public-private key pair A : (P_A, S_A)
Public-private key pair B : (P_B, S_B)
 F_A, F_B : (trapdoor) one-way functions of
 A , resp. B

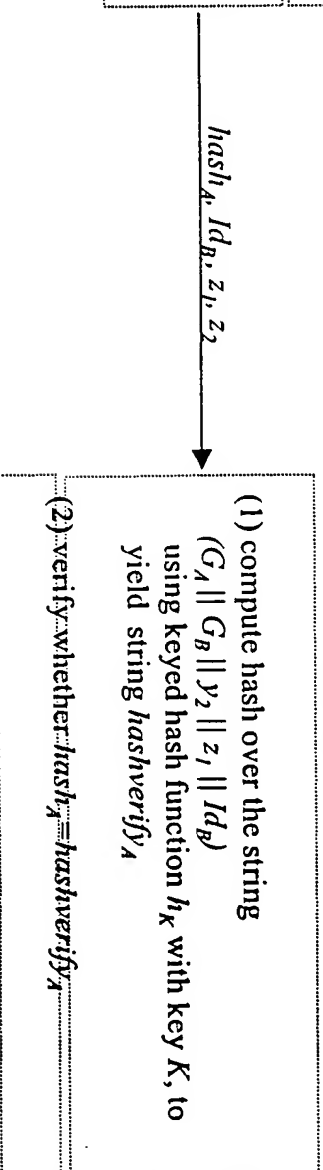


fig 4

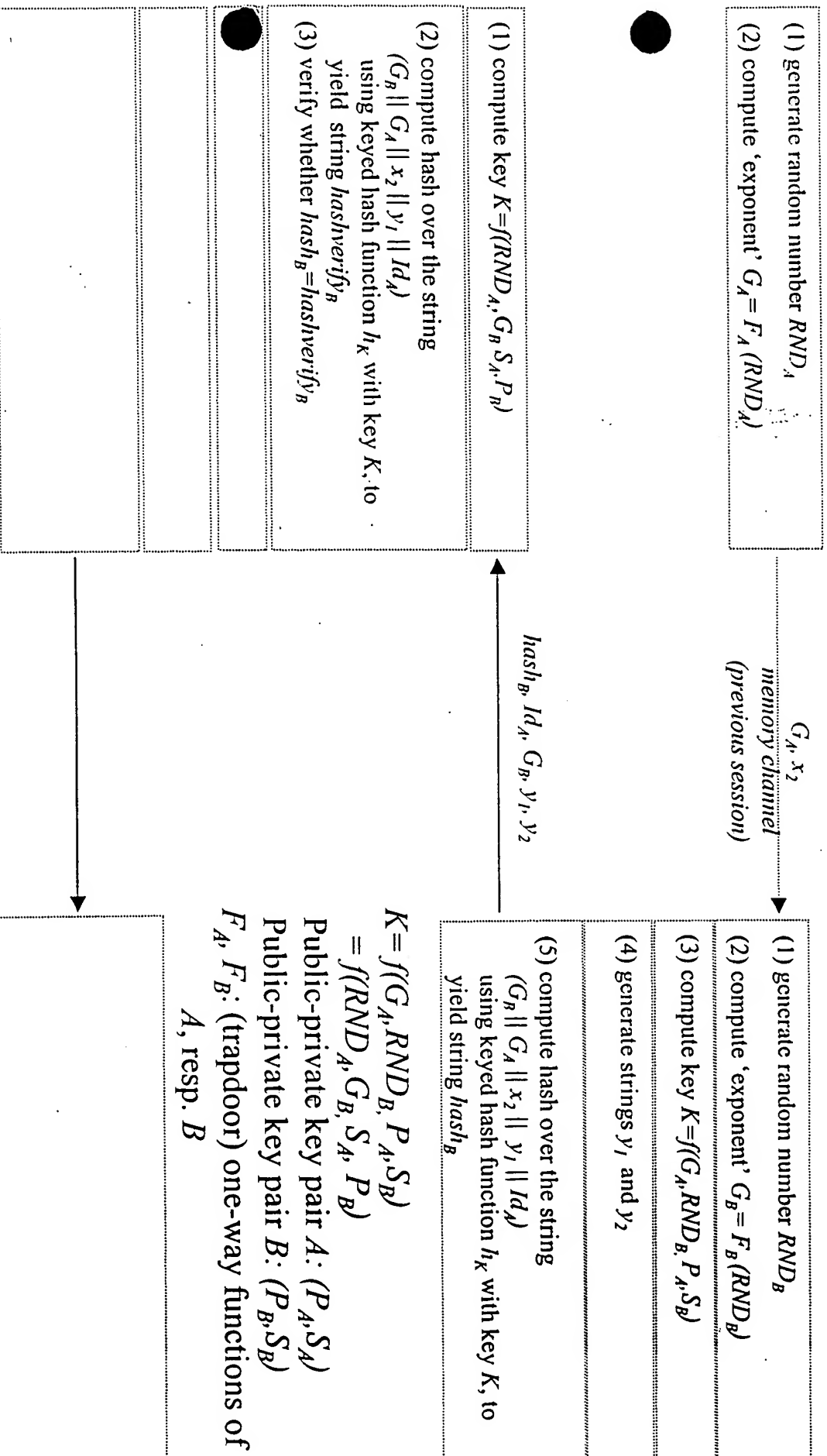
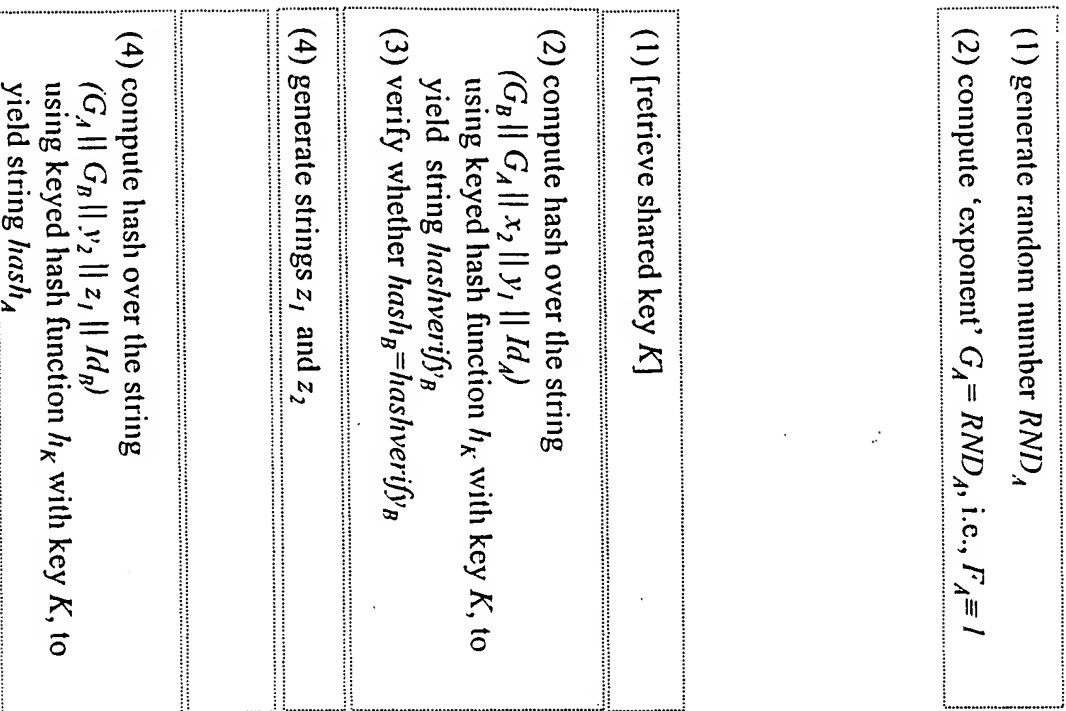


fig 5



G_A, x_2

$hash_B, Id_A, G_B, y_1, y_2$

$hash_A, Id_B, z_1, z_2$

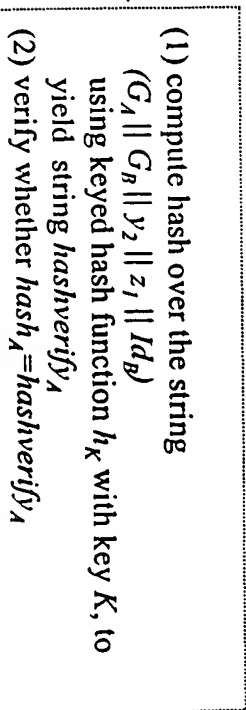
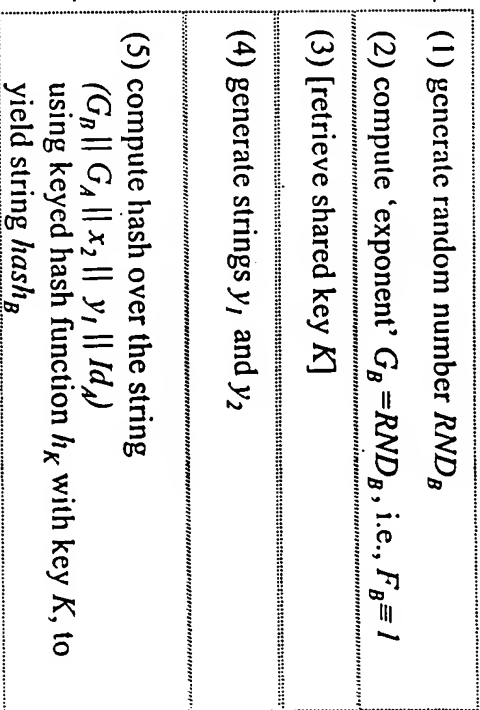


Fig 6

1-Pass Unilateral Symmetric Key Entity Authentication Protocol (1)

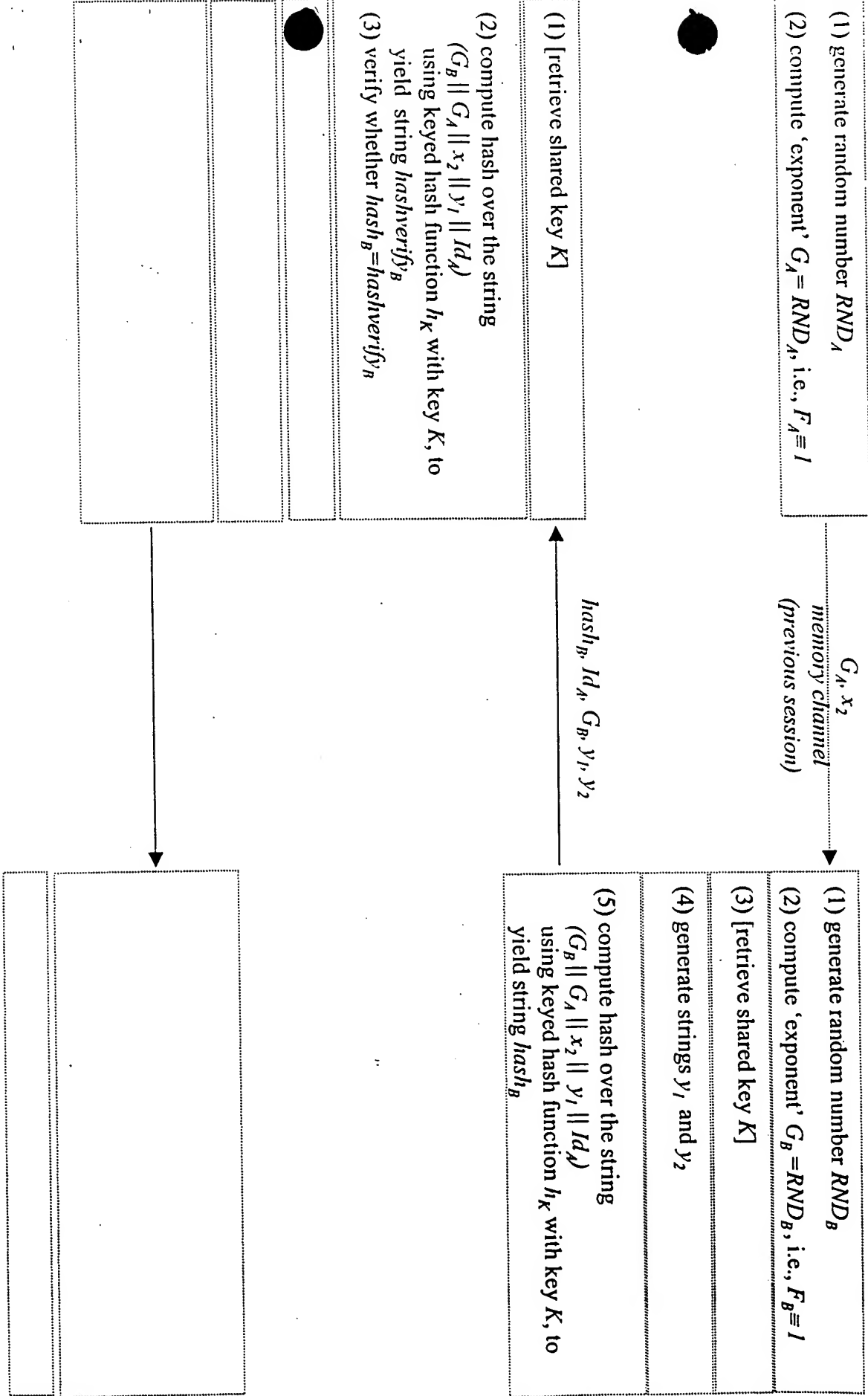


Fig 7